Ontario

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Ontario's Experience with Rubber Modified Hot Mix Asphalt

MERO-037

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Author(s)	Seyed Tabib, Masud Ahmed, Pamela Marks, Kai Tam, Chris Raymond Ontario Ministry of Transportation
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Ministry Contact	Materials Engineering and Research Office, Ontario Ministry of Transportation 1201 Wilson Ave., Room 238, Building C, Downsview, Ontario, Canada M3M 1J8 Tel: (416) 235-3715; Fax: (416) 235-3996
Abstract	Disposal of waste rubber tire is an environmental concern in Ontario. The use of scrap rubber tire as a modifier to hot mix asphalt (HMA) has been studied for many years, as a possible solution to waste disposal of scrap tires. Recognizing that road construction is an expensive process, it is important that pavement performance and durability are not compromised by the addition of new materials such as scrap tires. Between 1980 and 1995, Ontario Ministry of Environment (MOE) in cooperation with the Ministry of Transportation Ontario (MTO) and various Municipalities constructed over thirty test sections incorporating Crumb Rubber Modifier (CRM) into HMA to evaluate the performance of rubber modified asphaltic pavements. In 1997, MOE with support from MTO sponsored a study to evaluate the performance of rubber modified pavement projects constructed between 1980 and 1995 in Ontario. In 2003 an in-house survey was conducted by the MTO, mostly on the same projects, to gather updated information on their performance. Analyses of both study findings overwhelmingly indicate that the dry process is not appropriate for roadways with an Annual Average Daily Traffic (AADT) of 1000 or higher. Sections with the semi-wet process performed comparably to conventional HMA. Performance of sections with the wet process was superior to the other two processes and similar to or better than conventional HMA. In 2008, MTO built two 500 m trial sections on Highway 15 in Smiths Falls using the semi-wet process employing 1% of ambient as well as cryogenic ground CRM by weight of the mix. These sections will be subjected to annual performance review in comparison with the control Superpave HMA section. Initial findings support building additional trial sections in future using wet or semi-wet processes. So far, experience in Ontario has not shown rubber modified HMA to be a cost effective technology. Additional cost associated with the rubber modified HMA compared to the regular HMA ranged from 40-65%. This report overviews Ontario's three decades of experience with rubber modified HMA and provides recommendations for future considerations of this technology.
Key Words	Longitudinal joint, pavement deterioration, echelon paving, planning, design
Distribution	Unrestricted technical audience.

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Prepared by
Materials Engineering and Research Office
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1201 Wilson Avenue, Building C, Room 238
Toronto, Ontario, Canada M3M 1J8
Tel: (416) 235-3715; Fax (416) 235-3996

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Executive Summary

Disposal of enormous quantities of scrap rubber tires is a current environmental concern. The use of scrap rubber tire in Hot Mix Asphalt (HMA) has been looked at for many years. Since the early 1980s, the emphasis for this engineering technology began to focus on its potential as a solution to an environmental solid waste disposal problem.

Road construction is a costly process that has a significant impact on the environment through using large quantities of natural resources. As with any new technology, it is therefore important that the pavement performance and durability are not compromised by the addition of a new material such as scrap rubber tire in the asphalt mix. Between 1980 and 1995, the Ministry of Environment (MOE) in cooperation with the Ministry of Transportation Ontario (MTO) and various Ontario Municipalities constructed more than thirty test sections incorporating Crumb Rubber Modifier (CRM) into the HMA to evaluate the performance of rubber modified asphaltic pavement.

In 1997, a study conducted by John Emery Geotechnical Engineering Limited (JEGEL) was sponsored by MOE with support from MTO, to monitor many of the Ontario rubber modified asphalt pavement projects. In 2003, an in-house survey was conducted by MTO to gather updated information on the performance of test sections. California Department of Transportation (Caltrans) conducted a survey in 2004 about the experience of US Departments of Transportation (DOTs) with CRM technology.

Rubber modified asphalt projects in Ontario were mostly constructed on municipal roads with varying pavement structures and various traffic conditions. Limited performance data were available at municipalities during the 1997 and 2003 surveys. This study attempted to compile long term performance of the test sections based on the data found in 1997 JEGEL and 2003 MTO surveys. The compiled information was then used in the performance analysis. The rubber modified asphalt pavements were then categorized based on the performance and traffic volumes.

Analyses of both study findings on Ontario's pavement performance overwhelmingly indicate that the dry process is not appropriate for roadways particularly with an Annual Average Daily Traffic (AADT) of 1000 or higher. Most projects with higher AADTs that used dry process failed prematurely and required extensive maintenance. Sections with semi-wet process performed comparably to conventional HMA. Performance of sections with wet process was superior to the other two processes and similar to or better than conventional HMA. Caltrans survey on the use of scrap tire in pavement confirmed Ontario's findings. Due to limited success achieved with CRM using the dry process, this process is not recommended for use on MTO's provincial highways, which carry volumes higher than 1000 AADT.

In 2008, MTO built two trial sections of 500 m each on Highway 15 in Smiths Falls using semi-wet process employing ambient (i.e., freezing scrap rubber with liquid nitrogen

before grinding) as well as cryogenic (ground at room temperature or above) ground CRM. The objective was to further assess the performance of rubber modified HMA. The surface course and upper binder course in these sections contained 1% CRM by mass of the asphalt mix. These sections are MTO's first trial of rubber modified SuperPave mixes and will be subjected to annual performance review alongside a Superpave HMA control section. Future performance evaluations of these sections are needed before any conclusions on the long term performance of these sections can be drawn. Initial findings support building additional trial sections using the wet or semi-wet processes.

This report overviews Ontario's three decades of experience with rubber modified HMA and provides recommendations for future considerations for using CRM in HMA pavements.

Introduction

Disposal of waste rubber tires is an environmental concern in Ontario. According to the Used Tires Program Plan prepared by Ontario Tire Stewardship in February 2009, the current scrap highway tire generation is about 13.0 million Passenger Tire Equivalents (PTEs) of which about 0.8 million PTEs go to landfills [1].

More than thirty asphalt pavement trial sections modified with Crumb Rubber Modifier (CRM) were constructed in Ontario between 1980 and 1995, to evaluate the potential use of scrap rubber tire as a modifier to hot mix asphalt (HMA). The use of scrap rubber tire as a modifier or an additive in asphalt concrete has been reviewed for many years, as a possible solution to the solid waste disposal problem of scrap rubber tires. Road construction is a costly process that has a significant impact on the environment. As with any new technology, it is therefore important that the pavement performance and durability are not compromised by the addition of a new material such as scrap tire in the HMA.

Crumb rubber modified asphalt pavements in Ontario were constructed mostly on Ontario municipal roads with only a few sections constructed on provincial highways. Most of these trial pavements were constructed using the dry process. Several formal and informal evaluations have been carried out since these trial pavements were constructed.

In 2008, MTO built two 500 m trial sections on Highway 15 in Smith's Falls using the semi-wet process employing Ambient ground and Cryogenic ground crumb rubbers. Surface course and upper binder course in these sections contained 1% CRM by mass of the mix added to the hot mix in the asphalt plant. These sections are MTO's first trial of rubber modified SuperPave mixes and will be subjected to annual performance review in comparison with the Superpave HMA control section.

When evaluated in 2003, most of Ontario's rubber modified asphalt pavements had been in service for over 10 years and many of them had already been resurfaced. This report summarizes information from the past studies and provides an overall assessment of the rubber modified HMA pavements. Furthermore, the report provides some direction on how Ontario shall proceed in future with respect to rubber modified HMA.

Rubber Modified Asphalt Pavement Technology

CRM PREPARATION METHODS

CRM is produced from waste tires. The collected tires are cleaned, shredded, and some of the fibre and all the steel are removed. For the rubber to be used in HMA, the material must be further processed using ambient or cryogenic grinding or a combination of the two described below [2]:

Ambient Grinding

Method of processing where scrap tire rubber is ground or processed at or above ordinary room temperature. Ambient processing is typically required to provide irregularly shaped, torn particles with relatively large surface areas to promote interaction with the asphalt cement (AC).

Cryogenic Grinding

Process that uses liquid nitrogen to freeze the scrap tire rubber until it becomes brittle and then uses a hammer mill to shatter the frozen rubber into smooth particles with relatively less surface area. This method can be used to reduce particle size prior to grinding at ambient temperatures.

RUBBER MODIFIED HOT MIX ASPHALT

In general, the CRM can be added to the asphalt mix through three different processes: wet, dry, and semi-wet. Generally the dry process is limited to HMA applications, whereas the wet process has been applied to crack sealants, surface treatment, and HMA mixtures [3].

Dry Process

The dry process defines any method of adding CRM directly into the HMA mixing process, typically pre-blending the CRM with the heated aggregate before charging the mix with the AC. A variety of CRM gradations have been used, ranging from 6 mm to finer than 300 μm. The dry process will generate some reaction between very fine CRM added and AC, although limited. Common rate of CRM application is one percent by mass of the mix; although higher rates of up to two percent have also been reported.

Semi-Wet / Moist Process

This process is considered to provide improved pavement performance to that obtained with the dry process. In general, a finer CRM (passing 600 μm) is used and the mixing time is longer than the dry process. CRM application rate is between one and two percent by mass of the mix. Semi-wet or moist process will generate greater reaction between the CRM and AC than with the dry process, which results in partially modified AC. In other words, in the semi-wet process, some of the rubber will modify the AC while some will act as aggregate. Hence, semi-wet process lies somewhere between the wet and the dry process. This process has the advantage over the wet process in that no blending unit is required because direct feeding into the mixing process is possible.

Wet Process

The wet process defines any method that blends the crumb rubber with the AC before incorporating the AC into the HMA. This process is used to produce a modified AC product. The rubber component is typically between 12 and 20 percent by mass of total AC blend (or 0.6 to 1.0 percent by mass of HMA). CRM particles are usually finer than 2.36 mm. One of the main elements of the equipment necessary to achieve the wet process is the blending unit to digest the CRM with the parent AC. Blending unit must be capable of properly metering the CRM into the AC at the required proportion established by the mix design.

APPLICATION RATE OF CRM

Past studies in Ontario indicated that up to two percent of CRM could be added by mass to the HMA [4]. Two percent CRM by mass of HMA equates to four tires/tonne of HMA or about 1500 tires/lane km for a 40 mm lift of HMA. According to other estimates, CRM asphalt technology can incorporate from two to six tires into a tonne of HMA paving material, assuming that each passenger tire can produce about five kg of CRM [3].

COSTS ASSOCIATED WITH RUBBER MODIFIED ASPHALT

The cost of semi-wet process is approximately 40 percent greater than conventional HMA based on a specific CRM trial pavement constructed at Kirkland Lake, Ontario in 1994 [5].

Based on the trial sections constructed by MTO in conjunction with the MOE on Highway 2 in Thamesville in the 1990s, asphalt rubber mix containing No.10 mesh (2.00 mm) crumb rubber was approximately 65 percent more expensive than the standard HL4 mix and the recycled rubber mix was 40 percent more expensive than the standard recycled mix [6].

MTO's 2008 trial sections on Highway 15 Smith's Falls using semi-wet process indicated 50 percent higher cost than regular HMA.

Given the small quantities of rubber modified HMA produced in trials using a new technology, higher initial costs were anticipated. The actual cost of producing rubber modified asphalt is projected to be 20 percent higher than regular HMA. Grey County, Ontario has been successfully paving rubber modified asphalt over the past two decades. For most of their projects, the extra cost ranged from 15 to 20 percent more than conventional HMA. This included the main cost item which was the purchase of CRM.

California Contract Cost Data 2003 indicates that the weighted average initial cost of Rubberized Asphalt Concrete (RAC) mixes is about 16 percent higher than that of the conventional HMA. However, life cycle cost analyses have demonstrated that there are cost offsets for reduced maintenance and extended service life of crumb rubber modified pavements [7].

EFFECTS OF CRM ON HMA PROPERTIES AND PAVEMENT PERFORMANCE

In the late 70's, University of Toronto identified that an increase of approximately two percentage points in the AC content above normal optimum (e.g., from five to seven percent) along with 20 percent CRM (by weight of the AC in the mix) would enhance the HMA properties so that it would be more durable, have greater flexibility and slow down the rate of oxidation of the AC. However, findings from the two trials constructed by the MTO in 1980 on Highways 36 and 48, using dry process, were in contrast. In these trials, rubber modified mixes with higher AC content (7.0 percent on Highway 36 and 5.6 percent on Highway 48) performed poorer than conventional hot mix after eight years in service; whereas rubber modified mixes with lower AC content (i.e., 5.3 percent on Highway 36 and 4.3 percent on Highway 48) performed comparable to conventional hot mix section. The estimated life span of rubber modified pavement section with higher AC content was approximately 20 to 25 percent shorter than conventional hot mix section. It was concluded that, to achieve a durable rubber modified asphalt pavement, an optimum AC content was to be determined [8].

In general, studies conducted by the US Departments of Transportation (DOTs) indicate that rubber modification has a greater potential to resist reflective cracking, rutting, and fatigue than conventional HMA. Wet process mixes typically perform better than dry process mixes at resisting rutting, fatigue, reflective cracking, and ravelling. Gap-graded and open-graded CRM mixes typically perform the best for both wet and dry process CRM modification. Performance is further enhanced when relatively high contents of high viscosity binder can be accommodated in the mix [7].

Grey County, Ontario, who have been recycling scrap tires into their hot mix pavements since 1991, found that rubber modified asphalt allowed the pavement to be more flexible and therefore more crack resistant with an estimated extended pavement life of 20 percent. Grey County's success has been attributed to their precise quality control over a Closed Loop Recycling program that begins with tire rubber recovery and ends with the placement of rubber asphalt on municipal roads [9].

RECYCLABILITY OF RUBBER MODIFIED ASPHALT

A wide range of CRM paving materials can be successfully recycled. Several studies have been conducted to assess the emissions from recycling CRM materials. The overall results of emissions assessments indicate little difference and no apparent increase in risk from conventional HMA production [7]. Varieties of recycling technologies were considered in the studies including: full depth pavement reclamation, hot mix plant recycling, cold in-place recycling, and hot in-place recycling [10].

MTO in 1991 constructed a two km trial section on Highway 2 in Thamesville where existing rubber modified asphalt was milled and recycled at a hot mix plant at a ratio of 30 percent reclaimed asphalt and 70 percent new aggregate. The section was then paved with the recycled hot mix. Construction proceeded without major problems except severe material pickup by the pneumatic roller. Visual observations in 1992 revealed that the centreline joint in this section was opened up and some minor ravelling had occurred along the open joint. The plant emissions for the recycled mix were higher than the conventional HMA and, in some cases, exceeded the Ontario air quality criteria, especially for the particulate matters [6].

Evaluation of Ontario's Rubber Modified Asphalt Pavements

TRIAL SECTIONS BUILT IN ONTARIO FROM 1980 to 1995

Ontario's crumb rubber modified pavement trial sections, constructed from 1980 to 1995, followed three objectives:

1. Determine whether incorporating scrap tires in hot mix asphalt is environmentally acceptable;
2. Identify if pavements containing CRM can be recycled; and
3. Economic feasibility of the pavements modified with CRM.

Majority of these roads were constructed in the early 1990's by the municipalities, where old tires were ground up and added to the hot mix asphalt using the dry process.

The MOE with support from MTO sponsored a study in 1997, to monitor 29 of Ontario's rubber modified pavement sections constructed between 1980 and 1995 [5]. Under this study, detailed performance monitoring was conducted by John Emery Geotechnical Engineering Limited (JEGEL) for 15 crumb rubber modified asphalt pavement sections, consisting of:

- Visual inspections,
- Distress surveys,
- Deflection and frictional properties testing, and
- Pavement profile measurements.

The remaining 14 projects that were all constructed in 1993 underwent visual inspections only. The purpose of the performance monitoring was to assess Ontario's rubber modified asphalt projects. Their performance was compared with those of conventional pavements to determine the benefits attributable to the various rubber modified asphalt technologies, and to provide recommendations for future use of CRM in asphalt pavements in Ontario.

In 2003, a second survey was completed by the MTO staff. This in-house survey collected performance information on the rubber modified asphalt pavements, maintenance history, and traffic levels. The information was gathered from the respective municipal contacts via questionnaire, followed by verbal discussions for many of the sections. Updated information was not available for a number of sections.

Results of both studies are compiled in Table 1. Three following performance levels were used in Table 1 to express the overall performance of trials sections: **good, moderate and poor.**

GOOD	**means**	a service life greater than 10 years
MODERATE	**means**	a service life of about 10 years
POOR	**means**	a service life of less than 10 years

Trial sections in Table 1 are categorized on the basis of traffic level using the following: **AADT < 1000, 1000 ≤ AADT < 2000, and AADT ≥ 2000**.

Further details regarding adoption of the above criteria are provided later in Chapter 4 of this report.

1997 JEGEL STUDY

A follow up study was done in 1997 by JEGEL. The key findings from the study are as follows:

- Generally, sections constructed using dry process performed worse than sections constructed with conventional HMA. Predominant distress types observed included: ravelling, loss of coarse aggregate/CRM particles, construction joint cracking, longitudinal cracking, and transverse cracking.
- Pavement sections constructed using semi-wet process performed better than those constructed using the dry process and somewhat comparable to the conventional HMA.
- Relative performance of sections with wet process was generally similar to conventional pavement. Predominant distress types observed included: construction joint cracking, alligator cracking, longitudinal cracking, and transverse cracking some of which were not related to the CRM use. Moreover, it appeared that terminal blended CRM outperformed the on-site blend process.
- Although the wet process was generally superior to the dry process, lack of control sections at each trial site made it difficult to fully verify the technical merits of one process over the other. Therefore, only general comparisons were made based on the occurrence of visible distresses that can be directly attributed to rubber modified asphalt (such as ravelling).
- Significant additional cost is associated with crumb rubber modified asphalt pavements. It is estimated that large scale use of this technology and increased contractor experience would result in rubber modified asphalt mixes costing about 20 percent more than conventional HMA.

A more comprehensive summary of the information from 1997 JEGEL Report can be found in Appendix A.

Table 1. Performance of Ontario's Crumb Rubber Modified Asphalt Sections

Description, (Length, Construction Date)	Process	Maintenance/ Rehabilitation until 2003	Overall Performance Prior to Rehabilitation	Performance Category	AADT Category
Pelham, Roland Rd (2.1km, Nov 93)	Dry	Surface treated in 2002	Moderate segregation, some transverse & edge cracking.	**MODERATE**	**< 1000**
Wellington, County Rd 2 (2.2km, Oct 93)	Dry	Surface treated in 96 & resurfaced in 2003	Severe ravelling, potholes and rutting.	**POOR**	**1000 to 2000**
Wellington, County Rd 14 (3.4km, Oct 93)	Dry	Mill and overlay with HL4 in 1997	Very severe ravelling. Rutting and very poor riding quality.	**POOR**	**≥ 2000**
Peterborough, Armour Rd, Parkhill Rd northerly 1.8 km (1.8km, Oct 94)	Wet	No rehabilitation	Frequent longitudinal & transverse cracks.	**GOOD**	**≥ 2000**
Port Colborne, composting pad, landfill site on Elm St south of Forks Rd (Nov 93)	Dry	No rehabilitation	Few ravelling, no rutting or cracking.	**GOOD**	**< 1000**
Bobcaygeon, Hwy 36, Beatty to Twp 8th Line (Contract 79-32, Sep 80)	Dry	Resurfaced in 1991	Performance drastically dropped in 8 years. Extensive moderate cracks (longitudinal, edge, centerline and transverse) as per 1988 evaluation.	**POOR**	**≥ 2000**
Kirkfield, Hwy 48, Gravel Rd to Trent River/County Rd. 9 (Contract 79-85, Jul 80)	Dry	Resurfaced in 1995	In general, performance of this road was fair. According to the evaluation in 1988, there was moderate transverse cracking throughout.	**MODERATE**	**≥ 2000**
Kirkland Lake, Main St, Birch St southerly 325 m (0.3 km, Sep 94)	Semi-wet	No rehabilitation	Frequent longitudinal and transverse cracking	**MODERATE**	**< 1000**
New Liskeard, Whitewood Ave, Hwy 65 (0.76km, Jul 93)	Dry	Resurfaced in 1999	Ravelling. Crumb rubber segregated from exposed surface. This road began to fail shortly after placement.	**POOR**	**≥ 2000**
Northumberland County Rd 9, 1km east of County Rd 18 to County Rd 15 (2.7km, 1993)	Wet	No rehabilitation	Frequent ravelling and loss of aggregates and rutting. Frequent slight to moderate transverse and longitudinal cracking. Ride Comfort Rating was "FAIR".	**MODERATE**	**1000 to 2000**
Northumberland County Rd 18, County Road 74 northerly 1.7 km (1.7km, 1993)	Wet	No rehabilitation	Moderate ravelling and loss of aggregates and rutting. Slight transverse and center line cracking and severe longitudinal cracking. Ride Comfort Rating was "FAIR".	**MODERATE**	**≥ 2000**
Fort Frances, Old Shamble Rd (0.25km, Oct 93)	Dry	No rehabilitation	Extensive longitudinal joint failure. Slight aggregate loss but no potholes. No rutting.	**MODERATE**	**< 1000**
Fort Frances, Armit Ave (0.1km, Oct 93)	Dry	No rehabilitation	Slight aggregate loss, but no rutting or cracking.	**GOOD**	**1000 to 2000**
Grey County Rd 9, 4 km west of Hopeville to 3 km east of Hopeville (6.9km, Aug 95)	Dry & Wet	Unknown	No up to date information. In 1997, this section exhibited low severity ravelling, transverse and meandering cracking and performed moderately.	**MODERATE**	**< 1000**

Note: Data in Table 1 have been compiled from 1997 and 2003 studies

Table 1. (Continued)

Description, (Length, Construction Date)	Process	Maintenance/ Rehabilitation until 2003	Overall Performance Prior to Rehabilitation	Performance Category	AADT Category
Grey County Rd 9, 3 km east of Hopeville to County Rd 8 (7.1km, Oct 94)	Dry & Wet	Unknown	No up to date information. In 1997, this section exhibited low severity ravelling, transverse and meandering cracking and performed moderately.	**MODERATE**	**< 1000**
Grey County Rd 40, Hwy 6 to Desboro (11.2km, 93)	Dry	No rehabilitation	Frequent ravelling and longitudinal cracking along edges.	**MODERATE**	**1000 to 2000**
Grey County Rd 12 (Hwy 6 to Markdale) (12.3km, Nov 91)	Dry	Unknown	No up to date information. In 1997: moderate meandering cracking, alligator cracking, edge cracking and also frequent transverse cracking.	**MODERATE**	**< 1000**
Maryborough Sideroad 6 (Hwy 86 to Concession 3), (2.7km, Nov 93)	Dry	Surface treated in 2002	Few ravelling, few potholes. Centerline separation, few transverse cracks, meandering cracking, alligator cracking.	**MODERATE**	**< 1000**
Haldimand County, Regional Rd 55 (Reg Rd 9 to Reg Rd 20) (4.8km, Oct 90)	Dry	In 2000 and 2002	Severe ravelling, popping out of aggregate, patching. Alligator cracking and longitudinal cracking and severe transverse cracking.	**POOR**	**< 1000**
Norfolk County, Reg Rd 9, Villa Nova to Reg Rd 70 and Reg Rd 70 to Reg Rd 55 (3.3km+3.8km, Oct 90)	Dry	Extensive Maintenance from 1995-2000	Severe potholes. Center line cracking. Medium to high severity longitudinal, transverse, and alligator cracking.	**POOR**	**≥ 2000**
Hwy 400 (0.6 km north of Hwy 89 northerly 3 km) (0.5, Jul 90)	Wet	Resurfaced in 1996	Severe rutting, severe longitudinal & transverse cracks.	**POOR**	**≥ 2000**
Brantford, Park Rd North (Dunsdon St to Powerline Rd) (0.5, Oct 94)	Wet	No rehabilitation	Slight aggregate loss. Extensive longitudinal and transverse cracking	**POOR**	**1000 to 2000**
Barrie, Mazinaw Lake Rd South (1km, Oct 93)	Dry	Unknown	No up to date information. As per 1997 evaluation: moderate longitudinal cracking and construction joint and transverse cracking.	**MODERATE**	**< 1000**
Windsor, Wildwood Dr (0.3km, Nov 93)	Dry	No rehabilitation	Few ravelling. Frequent alligator cracking.	**GOOD**	**< 1000**
Windsor, Beachdale Rd (0.5km, Nov 93)	Dry	No rehabilitation	Few ravelling. Frequent alligator cracking.	**GOOD**	**< 1000**
Windsor, Esplanda Dr (0.4km, Nov 93)	Dry	No rehabilitation	Few ravelling. Frequent alligator cracking.	**GOOD**	**< 1000**
Grey County, County Rd 17 (4.4km)	Dry	No rehabilitation	Frequent rutting. Frequent longitudinal cracks. Heavy truck traffic on this road (due to quarry operation).	**MODERATE**	**1000 to 2000**
Thamesville, Hwy 2 (East of Hwy 21) (6.5km, 1990)	Dry	No rehabilitation	Slight aggregate loss on entire roadway. Slight rutting throughout. Moderate longitudinal and alligator cracking and frequent transverse cracking.	**MODERATE**	**≥ 2000**
Bentinck Twp, Sideroad 25 (3km, Oct 93)	Dry	No rehabilitation	Moderate transverse cracking & frequent longitudinal cracking.	**GOOD**	**< 1000**

Note: Data in Table 1 have been compiled from 1997 and 2003 studies

2003 MTO SURVEY

In-house Survey Conducted by MTO

Most of Ontario's rubber modified pavements were constructed in early to mid 1990's and their early performance was evaluated by JEGEL in 1997. As a continuum to evaluate their long term performance, MTO conducted an in-house survey in 2003. Through the 2003 MTO Survey, performance information was collected from the various respective Ontario municipalities and counties. Survey covered:

- Current traffic volume,
- Date of resurfacing,
- Pavement condition prior to resurfacing or major maintenance,
- General comments on performance of the section.

Some roads had already been rehabilitated (mostly resurfaced) at the time of survey due to their poor performance and it was noted that performance data for many of the resurfaced trial sections were not documented. Hence, some information was obtained through interviewing respective municipally staff.

Appendix B contains a summary of the information gathered in this survey.

Discrepancies detected by the 2003 MTO Survey

The following discrepancies or changes in jurisdiction from the JEGEL report were noted while summarizing the responses to the 2003 MTO survey:

- According to the local officials, the section on Highway 62 was not constructed with CRM;
- Updated information for the Bobcaygeon section constructed in the 1980s indicated that this road was under the Township of Galway-Cavindish-Harvey in 2003;
- 2002 local municipal traffic data for Highway 65 (New Liskeard, Whitewood Avenue) was 3350 AADT whereas JEGEL's 1997 study reported 9000 AADT. Lower traffic level was assumed for this analysis.
- Recent information was not available from Grey-County for the performance of Grey County Road 9 and Grey County Road 12 trials;
- Maryborough Sideroad 6 was referred to as Sideroad 7 in 1997 JEGEL Report. This road is under Mapleton Township;
- Trial section on Highway 400 is the only crumb rubber modified pavement that is still under MTO jurisdiction. This section was resurfaced in 1996;
- We were unable to locate the Mazinaw (Lake Road South) section, previously listed under Barrie Township in the 1997 JEGEL Report;
- MTO's Highway 2 section was transferred to the Municipality of Chatham-Kent in 1997.

Findings from 2003 MTO Survey

- Many of Ontario's rubber modified asphalt pavements were resurfaced by 2003.
- Three performance ratings of Poor, Moderate, Good were used to express overall performance of trial sections. Ratings can be found in Table 1.
- Information regarding the performance/condition of the trial sections, although limited in most cases, indicated that about one forth of these sections had a Good performance rating after an average of ten years. About half of the sections were rated Moderate and the remaining one forth rated Poor. Most predominant distresses in Moderate and Poor sections were moderate to severe ravelling, rutting, cracking, and potholes.
- Based on the limited information collected through the 2003 MTO Survey, no firm conclusion could be drawn regarding the superiority of the wet process over the dry process.

2008 MTO TRIAL SECTION ON HIGHWAY 15 SMITH'S FALLS

In summer 2008, two trial sections of 500 m each were built on Highway 15 in Smith's Falls, Ontario using semi-wet process employing Ambient and Cryogenic ground crumb rubbers. Surface course and upper binder course in these sections contained 1% CRM by mass of the mix. CRM was added to the hot mix in the asphalt plant. These sections are MTO's first Superpave mixes modified with CRM and will be subjected to annual performance review in comparison with the control Superpave hot mix section.

Pavement in these sections consisted of 40 mm rubber-modified Superpave 12.5 FC1 over 50 mm rubber-modified Superpave 19 over 50 mm non-modified Superpave 19. An ultra fine CRM, passing 300 μm sieve, was specified for this job.

Construction Issues

The following issues were noted during the construction of the rubber-modified trial sections on Highway 15:

- Fine particles in the mix were occasionally picked up by the pneumatic roller during compaction. These particles eventually detached and landed on the pavement surface.
- Slight segregation was noted along the centerline joint.
- Visible fumes were noted emitting from the rubber modified hot mix in the hauling truck and the paver. Odour was slightly stronger than regular hot mix. Rubber modified asphalt was found to be harder to rake.
- Coring crew noted that coring through the rubber modified asphalt was remarkably harder than coring of the regular HMA. Extraction of the core from the barrel was also more cumbersome.
- Quality control/assurance results on asphalt samples indicated deviations in air voids, VMA, and AC content particularly for the Cryogenic Superpave 12.5 FC1 section. While this is not considered to be related to the addition of CRM to the mix, it may impact performance.

Pavement Condition after Construction in 2008

After construction in summer 2008, the pavement surface on the trial sections was observed as quite dense and smooth, free from noticeable segregation or roller marks (except slight segregation/streaking along the centreline). Ride was excellent without rippling or shoving.

Pavement Condition in 2009

About one year after construction, in May 2009, trial sections on Highway 15 were visually evaluated for distress manifestation.

Ambient Rubber Section

Following pavement distress types were noted in the Ambient Rubber section:

- Frequent slight centreline cracking – about 20 percent of section length (Figure 1).
- Few slight coarse aggregate loss and ravelling (Figure 1).
- Few slight midlane longitudinal cracking (Figure 2).
- Few very slight transverse cracking. Construction joints at the south limit opened up (Figure 2).
- Few very slight wheel track longitudinal cracking (Figure 2).

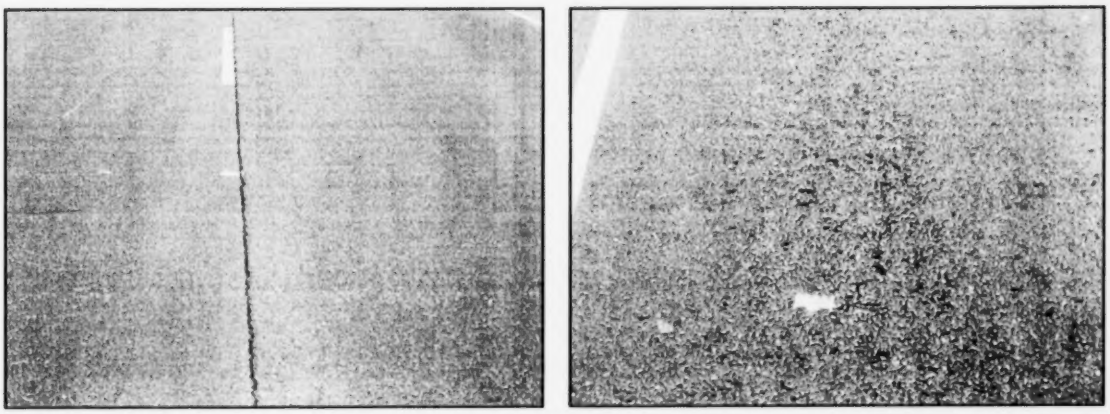

Figure 1. Centreline joint has partially opened up; localized slight coarse aggregate loss is evident in Ambient Rubber Section – 1 year after construction

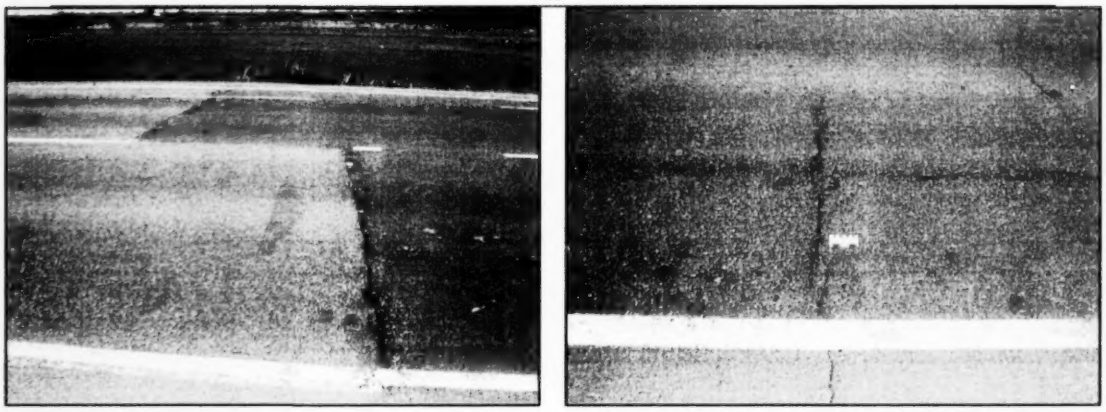

Figure 2. Construction joints have opened up; transverse and longitudinal cracks have formed in Ambient Rubber Section – 1 year after construction

Cryogenic Rubber Section

Following pavement distress types were noted in the Cryogenic Rubber section:

- Construction joints at the south limit opened up (Figure 3).
- Few slight coarse aggregate loss and ravelling (Figure 3).

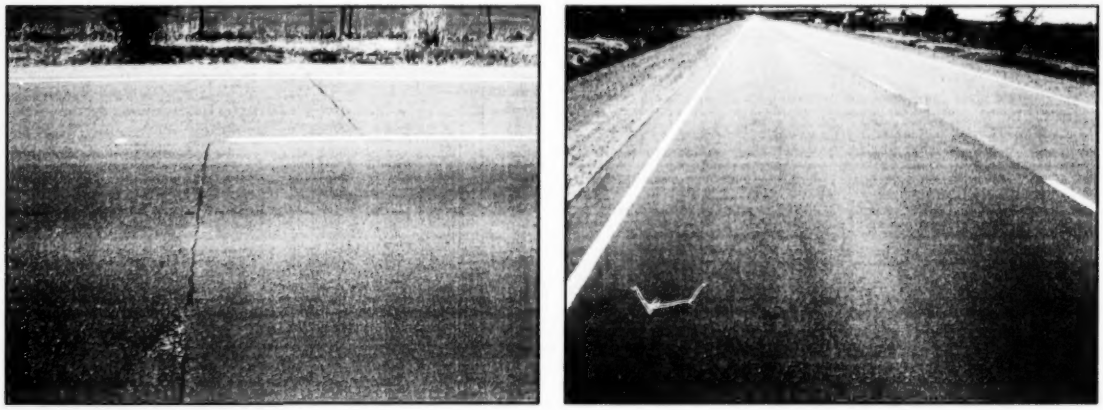

Figure 3. Construction joints have opened up; localized slight coarse aggregate loss is evident in Cryogenic Rubber Section – 1 year after construction

Superpave 12.5 FC1 Control Section, 495 m

Following pavement distress types were noted in the Control section:

- Construction joints at the south limit partially opened up (Figure 4).
- Few very slight to slight coarse aggregate loss (Figure 4).

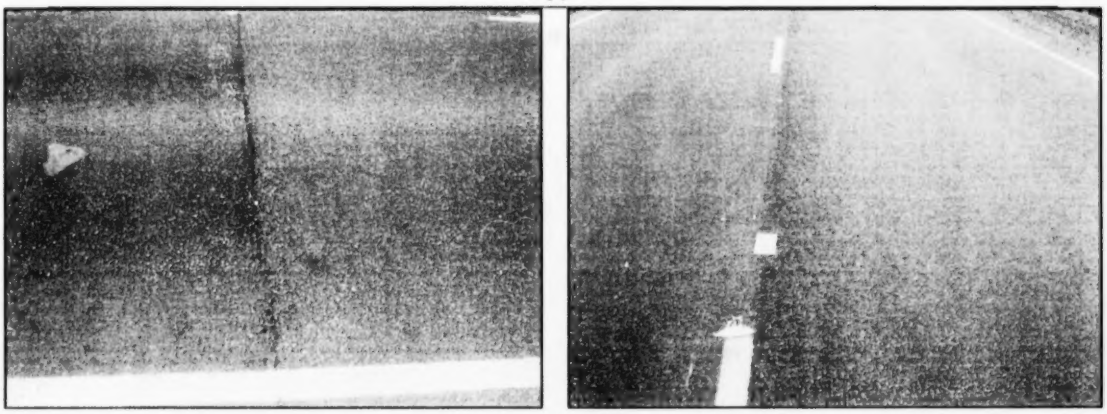

Figure 4. Construction joints have partially opened up; localized slight coarse aggregate loss is evident in Control Section – 1 year after construction

CALIFORNIA DEPARTMENT OF TRANSPORTATION SURVEY AND MTO QUESTIONNAIRE

California Department of Transportation (Caltrans) conducted a survey in 2004, involving other US Departments of Transportation (DOTs), entitled 'Scrap Tire Use in Paving Application Survey' [11]. Forty four state agencies responded to the survey. The survey results were circulated in October 2004. Later in December 2004, MTO sent a questionnaire to the seven DOTs who used CRM in HMA and obtained detailed information about their experience with rubber modified asphalt. Results of the MTO query are given in Appendix C. A summary of the findings follows:

- 37 of 44 DOTs were not using CRM in the hot mix asphalt pavement at the time of the survey.
- Only five of 44 DOTs were using crumb rubber modified asphalt pavement on regular basis, and another two DOTs were using the technology experimentally.
- Five of 44 DOTs found the wet process suitable for wearing courses (mainly friction courses and chip seal) even in high traffic volume pavements.
- None of the seven DOTs who were either using or experimenting with this technology have adopted the dry process. The dry process had failed in the past and was no longer being considered for use.

Assessment

RUBBER MODIFIED PAVEMENTS CONSTRUCTED IN 1980-1995

Compilation of Information

Twenty nine (29) rubber modified trial sections were evaluated under a 1997 JEGEL study. This involved a detailed performance evaluation for 15 sections and visual inspections only for the other 14 sections. Lack of control sections at most of sections made it difficult to evaluate the technical merit of the CRM technology and different processes. Many of the pavements were resurfaced prior to 2003, and could not be formally evaluated. In 2003, an in-house survey was conducted by the MTO, mostly on the same projects, to gather updated information on their performance. Prior to drawing any conclusions, it was necessary to compile information from both studies given in Appendices A and B. Table 1 provides a compilation of both surveys, describing the performance of each rubber modified pavement section constructed in Ontario between 1980 and 1995.

Pavement Service Life

Due to lack of sufficient information pertaining to pavement construction details for each of these trial sections, an average service life of ten years was assumed for rubber modified asphalt pavements constructed during this period in Ontario. This assumption was necessary as in many cases, detailed information on their structural design, Equivalent Single Axle Load (ESAL), construction/rehabilitation information, etc. were unavailable.

Most of the rubber modified asphalt pavements were constructed between 1990 and 1995. In 1996-97, when the first evaluation was completed, the pavements were about one-third to half way through their assumed service life (three to five years old) and during the 2003 evaluation they were at their assumed end of service life. Table 1 includes comments regarding the performance of each rubber modified section based on the available data and assumed 10-year life expectancy.

Methodology and Overall Performance

Ontario's rubber modified trials were built on roadways with different traffic levels and pavement structures. Moreover, there were no control sections for direct comparison of their performance. To simplify the overall performance analysis, trial sections were categorized on the basis of traffic level, since traffic is one of the main factors affecting pavement performance. In general, the traffic on most of the trial sections was under 2000 AADT. Therefore, sections were grouped based on the following traffic levels:

AADT < 1000 **1000 ≤ AADT < 2000** **AADT ≥ 2000**

As mentioned earlier, pavement performance was evaluated for each project once in 1997 at the assumed one-third to half of service life and once again in 2003 at the assumed end of service life. All information has been compiled in Table 1 to provide an overall picture of each section's condition. Table 1 uses the three following performance levels to assess the sections:

GOOD	**means**	a service life greater than 10 years
MODERATE	**means**	a service life of about 10 years
POOR	**means**	a service life of less than 10 years

Based on the information obtained and using the methodology described above, the overall performance was Good to Moderate for sections with less than 2000 AADT; and Poor for sections with 2000 or more AADT as summarized in Table 2 below:

Table 2. Performance Assessment of Rubber Modified Asphalt Pavements in Ontario based on Different Traffic Levels

Traffic-Level	Number of Trial Sections		
	GOOD	MODERATE	POOR
AADT < 1000	5(D)	7(D), 2(W), 1(S)	1
1000 ≤ AADT <2000	1(D)	2(D), 1(W)	1(D), 1(W)
AADT ≥ 2000	1(W)	2(D), 1(W)	4(D), 1(W)

D = Dry S = Semi-wet W = Wet

PERFORMANCE OF 2008 MTO HIGHWAY 15 TRIALS

Rubber trials on Highway 15 are about one year old and longer evaluation period with more extensive data for several years is needed before any conclusive remarks regarding performance of rubber modified pavements can be made. So far, Ambient Rubber Section appears to be under-performing while Cryogenic Rubber and Control sections are performing comparably. Review of QC/QA data revealed low AC content and excessive air voids in the Ambient Section that could be among the reasons for early distress formation in this section. Table 3 below compares asphalt cement and air voids contents between surface course mixes used in the test sections:

Table 3. Asphalt Cement and Air Voids Contents

Mix Type	Asphalt Cement Content (Average)			Air Voids (Average)			
	Mix Design	QC	QA	Mix Design	QC	QA	Referee
Superpave 12.5 FC1 Ambient	5.00	4.60-4.73 (4.68)	4.87-5.29 (5.09)	4.0	3.5-5.5 (4.3)	4.7-6.6 (5.8)	3.5-5.4 (4.2)
Superpave 12.5 FC1 Cryogenic	5.10	5.31-5.43 (5.37)	4.94-5.35 (5.21)	4.0	2.0-2.2 (2.1)	1.0-1.9 (1.4)	none
Superpave 12.5 FC1 Control	5.20	4.89-5.18 (5.01)	4.96-5.66 (5.21)	4.0	2.7-5.5 (4.4)	2.8-5.5 (4.0)	none

Note: Value in bracket is mean value; QC means quality control; QA means quality assurance.

Conclusions

This report is based mainly on the information collected in 1997 and 2003 on the performance of rubber modified trial sections constructed in the 1980's and 1990's in Ontario. Lack of control sections and regular monitoring made evaluation of these sections a difficult task. Caltrans Survey 'Scrap Tire Use in Paving Application' and subsequent information collected by the MTO from other transportation agencies are also included in this report. Following conclusions can de drawn from the findings:

- Incorporation of CRM into the HMA has been tried for many years to partially solve the scrap tire disposal problem. However, construction pavement performance and cost are key issues that must be addressed before adopting this technology. So far, experience in Ontario has not proven rubber modified asphalt to be a cost effective technology.

- Cost for rubber modified asphalt is much higher than conventional HMA. Initial construction cost of a rubber modified asphalt pavement could be somewhere from 16 to 65 percent higher than the regular hot mix asphalt. Some of these costs are due to the current small scale use of rubber modified HMA.

- Grey County, Ontario, have been recycling scrap tires into the hot mix pavements since 1991. They have found that rubber modified asphalt allows the pavement to be more flexible and therefore more crack resistant with estimated extended life of 20 percent. Their success has been attributed to their precise quality control over a Closed Loop Recycling program.

- In Ontario, rubber modified HMA using the dry process has failed prematurely and requires extensive maintenance unless traffic volumes were below 1000 vehicles per day.

- Based on the compiled information and using the methodology described in this paper, the overall performance of the sections was Good to Moderate for sections with less than 2000 AADT, and Poor for sections with greater than 2000 AADT.

- A Survey conducted by Caltrans on the use of scrap tire in pavement along with MTO's follow-up questionnaire confirm Ontario's finding that the dry process is not as promising a technology for addition of CRM into HMA. The wet process appears promising although it has a higher initial cost. However, considering life cycle cost of the pavement, wet process makes economic sense. Five of 44 US DOTs are successfully using wet process in friction courses and chip seals, even on high traffic volume roads, and another 2 US DOTs are using this technology on an experimental basis. The use of semi-wet process offers a good compromise for cost effectiveness, ease of construction, and performance.

- MTO built two trial sections on Highway 15, Smith's Falls in 2008 incorporating Ambient and Cryogenic ground CRM using a semi wet process. These trials involved the use of Superpave asphalt mixes. After one year in service, the Ambient Rubber

Section is performing the worst with slight centreline and midlane cracks, very slight transverse and wheel track cracks, and slight coarse aggregate loss/ravelling. The Cryogenic Rubber and Control sections are performing well. Centreline joints are intact and no cracking is present. Future performance evaluation of these sections is needed before any firm conclusions can be drawn. Initial cost of these sections was about 50 percent higher than regular hot mix asphalt.

Recommendations

Given the findings from Ontario's rubber modified trial sections and experience of the US DOTs, the following recommendations are being made:

- MTO should conduct trials with dry process only on pavements with low traffic volumes (less than 1000 AADT). Parking lots are among possible locations for this technology.
- To better evaluate the performance of rubber modified asphalt in Ontario, more trial sections should be constructed using the wet and semi-wet processes. Performance monitoring along with life cycle cost analysis are needed to support any decisions with regards to the adoption of this technology in Ontario.
- Any new trial sections must be accompanied with control sections to enable fair comparison.
- Recyclability of rubber modified asphalt needs to be further studied focusing on the recycling ratio and emissions.
- Laboratory research would be a good tool to identify the suitable range for CRM gradation and application rate.
- Based on the past experience and laboratory results, specifications should be developed pertaining to the rubber modified asphalt mixes.

References

[1] Ontario Tire Stewardship. "Used Tires Program Plan", Waste Diversion Ontario (February 27, 2009).

[2] California Department of Transportation. "Asphalt Rubber Usage Guide", Report MS #5, Division of Engineering Services, Materials Engineering and Testing Services, Sacramento, California (2003).

[3] Heitzman, M. "Design and Construction of Asphalt Paving Materials with Crumb Rubber Modifier", Transportation Research Record, 1339, 1-8 (1992).

[4] Fromm, H.J. "Rubber Asphalt Test Roads Progress Report 1981", Report MSP-81-02, The Policy Planning and Research Division, Ontario Ministry of Transportation and Communications (1981).

[5] John Emery Geotechnical Engineering Limited. "Performance Monitoring of Rubber Modified Asphalt Demonstration Projects", ISBN 0-7778-7207-2, Final Report for the Waste Reduction Branch of the Ontario Ministry of Environment (1997).

[6] Aurilio, V. "Experimental Hot Mix Pavement with Scrap Tire Rubber at Thamesville, Ontario – Report # 2 Recycling Asphalt Rubber Mix", Proceeding, Canadian Technical Asphalt Association, 38, 51-76 (1993).

[7] California Department of Transportation. "Use of Scrap Tire Rubber – State of the Technology and Best Practices", Materials Engineering and Testing Services, Office of Flexible Pavement Materials, Sacramento, California (2005).

[8] Lynch, D.F. "Status letter on visual condition of rubber trial sections on Highways 36 and 48", MTO Bituminous Section (April 11, 1989).

[9] Marks, P. "Old Tires, New Highways: Rubberized Asphalt Pavement", Ministry of Transportation Road Talk, Volume 14, Issue 1 (Winter 2008).

[10] California Department of Transportation. "Feasibility of Recycling Rubber-Modified Paving Materials", Materials Engineering and Testing Services, Office of Flexible Pavement Materials, Sacramento, California (2005).

[11] California Department of Transportation. "Scrap Tire Use in Paving Application", Survey Results Circulated in October 2004.

Appendix A: Ontario Rubber Modified Trial Pavements and Their Performance – Summarized from 1997 JEGEL Report

Sec -tion	Location	Description	Mix Type	Length (km)	Const. Date	Process	AADT	CRM Type & Size	PCI (1997)	Last Evaluation	Pavement Performance According to 1997 JEGEL Report, And Other Comments
1	CR - Pelham	Roland Road	--	2.1	Nov-93	Dry	200 to 300	Ambient	--	1997	Station 0+800 from east project limit has low severity edge cracking extending from the outside wheel path to the edge of pavement. Station 1+300 has low severity construction joint and transverse cracks as well as few slight ravelling.
2	CR - Wellington County	County Road 2	--	2.2	Oct-93	Dry	550	Cryogenic	--	1997	Localized areas of severe ravelling have occurred, resulting in the formation of potholes. Construction joint cracking is also prevalent. Fair to good condition.
3	CR - Wellington County	County Road 14	--	3.4	Oct-93	Dry	--	Cryogenic #10 mesh	--	1997	Localized areas of severe ravelling have occurred, resulting in the formation of potholes. Construction joint cracking is also prevalent. Fair to good condition.
4	ER - Peterborough, Armour Road	Armour Road, Parkhill Road northerly 1.8 km	--	1.8	Oct-94	Wet -- Termi -nal	6300	Cryogenic #60 mesh	94	1997	Low severity longitudinal, transverse and meandering cracking.
5	ER - Port Colborne	Composting Site	HL3 & HL8	1 ha	Nov-93	Dry	N/A	Cryogenic		1997	Exposed portion of the pad is in excellent condition with localized minor ravelling.
6	NER - Kirkland Lake, Main Street	Birch Street to 325 m south, structure: 1.5 m Gran B; 150 mm Gran A; 80 mm HL-4	HL-4	0.3	Sep-94	Modified Dry	600	Cryogenic # 30 mesh	97	1997	Low severity transverse cracking, alligator cracking and edge cracking.
7	NER - New Liskeard	Whitewood Avenue / Highway 65	HL-4	0.76	Jul-93	Dry	9000	Cryogenic	--	1997	Localized wheel path ravelling and some crumb rubber has become dislodged from the surface and is noticeable in the gutter.

Appendix A: Ontario Rubber Modified Trial Pavements and Their Performance – Summarized from 1997 JEGEL Report

Sec -tion	Location	Description	Mix Type	Length (km)	Const. Date	Process	AADT	CRM Type & Size	PCI (1997)	Last Evaluation	Pavement Performance According to 1997 JEGEL Report, And Other Comments
8	NWR - Northumberland County Rd 9	1 km east of County Rd 18 to County Rd 15	--	2.7	93	Wet -- Termi -nal	--	Cryogenic	92	1997	Low severity construction joint cracking, longitudinal cracking, alligator cracking and edge cracking throughout, with localized minor low to medium severity transverse cracking and medium severity meandering cracking. Small amount of ravelling and patches.
9	NWR - Northumberland County Rd 18	County Road 74 to 1.7 km North	--	1.7	93	Wet -- Termi -nal	--	Cryogenic	84	1997	Low severity construction joint cracking, longitudinal cracking, alligator cracking and edge cracking throughout, with localized low to medium severity transverse cracking and medium severity meandering cracking. Small amount of ravelling and patches.
10	NWR - Fort Frances	River Road	HL-4	0.25	Oct-93	Dry	300	Ambient		1997	Very good condition with slight aggregate loss in localized areas.
11	NWR - Fort Frances	Armit Avenue	HL-4	0.1	Oct-93	Dry	1000	Ambient		1997	Very good condition with slight aggregate loss in localized areas.
12	SWR - Grey County Road 9	4 km west of Hopeville to 3 km east of Hopeville (4 different sections)	HL-4	6.9	Aug-95	Wet	200 to 500	Cryogenic	100	1997	One section exhibits low severity ravelling throughout. Low severity transverse cracking, low to medium severity longitudinal and meandering cracking.
						Dry		#10 mesh	100	1997	Low severity transverse cracking, meandering cracks, ravelling associated with loss of fine aggregate.
						Wet/Dry		# 10 mesh	96	1997	Low severity transverse cracking, low to medium severity longitudinal and meandering cracking.
						Control			100	1997	Low severity transverse cracking, low to medium severity longitudinal and meandering cracking.
13	SWR - Grey County Road 9	3 km east of Hopeville to County Road 8 (5 different sections)	HL-4	7.1	Oct-94	Wet -- Termi -nal	200 to 500	Cryogenic	98	1997	Slight aggregate loss
						Wet -- On-site			96	1997	Slight aggregate loss. Low severity ravelling
						Dry			87	1997	Low severity construction joint cracking for the full length of the section, and low severity edge cracking.
						Control # 1			95	1997	Slight aggregate loss. Low severity edge cracking.
						Control # 2			88	1997	Slight aggregate loss. Low severity edge cracking.

Appendix A: Ontario Rubber Modified Trial Pavements and Their Performance – Summarized from 1997 JEGEL Report

Sec -tion	Location	Description	Mix Type	Length (km)	Const. Date	Process	AADT	CRM Type & Size	PCI (1997)	Last Evaluation	Pavement Performance According to 1997 JEGEL Report, And Other Comments
14	SWR - Grey County Road 4	Highway 6 to Desboro	--	11.2	93	Dry	200 to 400	Combi -nation	84	1997	Low to medium severity construction joint cracking for the full length of the section, and low to medium severity edge cracking and longitudinal cracking and small amount of low to high severity transverse cracking. Ravelling, patching and potholes were also evident.
15	SWR - Grey County Road 13	Highway 4 to Eugenia	HL-4 surface	2.7	92	Dry / CIR	500 to 800	Cryogenic #4 mesh	96	1997	Low severity longitudinal, construction joint and meandering cracking. Localized low severity ravelling, and low to medium severity transverse cracking.
16	SWR - Grey County Road 12	Highway 6 to Markdale	HL-4	12.3	Nov-91	Dry	200 to 400	Ambient #10 mesh	84	1997	Low to medium severity meandering cracking, alligator cracking and edge cracking, with some low severity transverse and construction joint cracking.
17	SWR - Maryborough Sideroad 7	Highway 86 to Concession 3	HL-4	2.7	Nov-93	Dry	500	Cryogenic #10 mesh	85	1997	Low severity ravelling and transverse cracking, and few alligator cracking and edge cracking.
18	SWR - Haldimand-Norfolk Regional Rd 55	Regional Rd 9 to Regional Rd 20	HL-3	4.8	Oct-90	Dry	--	Cryogenic #10 mesh	74	1997	Low to medium severity longitudinal and low to high severity transverse cracking, low to medium severity construction joint cracking, alligator cracking, ravelling and patching.
19	SWR - Haldimand-Norfolk Regional Rd 9	Villa Nova to Regional Rd 70	HL-3	3.3	Oct-90	Dry	--	Cryogenic #10 mesh	83	1997	Low to medium severity longitudinal and transverse cracking, extensive low to medium severity construction joint cracking, medium severity meandering cracking, alligator cracking, ravelling and patching.
20	SWR - Haldimand-Norfolk Regional Rd 9	Regional Rd 70 to Regional Rd 55	HL-3	3.8	Oct-90	Dry	--	Cryogenic #10 mesh	71	1997	Low to high severity longitudinal and transverse cracking, extensive low to medium severity construction joint cracking and meandering cracking, and minor localized alligator cracking and patching.
21	SWR - Highway 400	0.6 km north of Highway 89 to 3 km North	--	0.5	Jul-90	Wet -- On-site	36000	Cryogenic, #80 mesh	--	1997	Longitudinal and transverse cracking that was attributed to age hardening of the asphalt cement. Transverse cracking was observed at regular 20 to 25 m intervals.
22	SWR - Brantford, Park Road North	Dunsdon Street to Powerline Road	--	0.5	Oct-94	Wet – Termi -nal	9500	Cryogenic #40 - #60 mesh	85	1997	Low severity longitudinal, transverse and meandering cracking, throughout.
23	SWR - Barrie Township	Mazinaw Lake Road South	--	1	Oct-93	--	100	#20 to 30 mesh	--	1997	Moderate severity longitudinal cracking and construction joint and transverse cracking.

Appendix A: Ontario Rubber Modified Trial Pavements and Their Performance – Summarized from 1997 JEGEL Report

Sec -tion	Location	Description	Mix Type	Length (km)	Const. Date	Process	AADT	CRM Type & Size	PCI (1997)	Last Evaluation	Pavement Performance According to 1997 JEGEL Report, And Other Comments
24	SWR – Windsor	Wildwood Drive	--	0.3	Nov-93	Dry	500	Cryogenic	--	1997	Fair to good condition with minor construction joint cracking and some alligator cracking.
25	SWR – Windsor	Beachdale Road	--	0.5	Nov-93	Dry	500	Cryogenic	--	1997	Fair to good condition with minor construction joint cracking and some alligator cracking.
26	SWR - Windsor	Esplanda Drive	--	0.4	Nov-93	Dry	500	Cryogenic	--	1997	Fair to good condition with minor construction joint cracking and some alligator cracking.
27	SWR – Cambridge	Stanley Street	HL-4 base and conventi onal surface	0.5	Nov-93	Dry	200 to 300	Cryogenic #16 mesh	--	1997	Road in excellent condition. Only base course is RMA. The surface course, completed in 1994 is conventional asphalt.
28	SWR - Grey County	County Road 17	--	4.4	N/A	Dry	2000	N/A	--	1997	Generally in fair to good condition. Localized low severity edge cracking, alligator cracking near centreline of road.
29	SWR – Bentinck Township	Sideroad 25	HL-4	3	Oct-93	Dry	500	Cryogenic #16 mesh	--	1997	Generally, in very good condition with localized moderate severity transverse crack, slight shoulder drop-off, and low severity longitudinal crack.

Note:

1. The terms used to describe the CRM pavement locations with respect to MTO Regions are:
CR = Central Region
ER = Eastern Region
SWR = Southwestern Region
NER = Northeastern Region
NWR = Northwestern Region.

Appendix B: Performance of Ontario Rubber Modified Pavements Prior to Resurfacing --- 2003 MTO Survey

Section (Note 1)	Location	Description	Mix Type	Length (km)	Const. Date	Status in 2003	Traffic in 2003 / Prior to Re-surfacing	Ride Quality in 2003 or Prior to Resurfacing				Observation by the Local Officials And General Comments
								Ravelling	Rutting	Cracking	Other	
1	CR - Pelham	Roland Road	--	2.1	Nov-93	12 mm Surface Treatment in 2002	AADT--300 to 500	Moderate Segregation (aggregates popping out & so small holes all over)	No rutting	Some transverse cracking and edge cracking		According to the local officials, the popping out of aggregate may be because of the poor bonding due to the presence of crumb rubber. According to them, crumb rubber asphalt pavement is expensive and has negative aspects.
2	CR - Wellington County	County Road 2	--	2.2	Oct-93	Section was re-paved in June-2003 (50 mm HL4). Earlier surface treatment applied in 1996 as there was ravelling.	1000	Severe ravelling and potholes, requiring some cold-mix patching and surface treatment in 1996.	Rutting of magnitude 10 to 20 mm, along entire length	Few cracking	Poor ride quality	Within few weeks of construction, the road required some attention but budget constraint delayed re-paving until 2003. This CRM road performed poorly (requiring additional costs to surface treat as holding strategy).
3	CR - Wellington County	County Road 14	--	3.4	Oct-93	In 1997, the County milled off the crumb rubber asphalt and placed 50 mm HL4 due to ravelling & rutting.	2000	Very severe ravelling	Rutting throughout the length of the road	Few cracking	Very poor riding quality	Ravelling and rutting presented a safety concern. The end result was a product that only lasted about 1/3 to 1/2 the life expectancy of regular asphalt.
4	ER - City of Peterborough, Armour Road	Armour Road, Parkhill Rd to 1.8 km North	--	1.8	Oct-94	Still exists (until 2003)	AADT -- 8000	No ravelling and no aggregate loss.	No rutting	Slight transverse cracking at 2 to 4m intervals. Slight intermittent longitudinal cracking 1.5 to 1.8m from centreline.	These cracks appear to be reflective cracking from the old underlying pavement.	Performing very well so far. Both crumb rubber section and non-rubberized section are performing similarly.

Appendix B: Performance of Ontario Rubber Modified Pavements Prior to Resurfacing --- 2003 MTO Survey

Section (Note 1)	Location	Description	Mix Type	Length (km)	Const. Date	Status in 2003	Traffic in 2003 / Prior to Re-surfacing	Ride Quality in 2003 or Prior to Resurfacing				Observation by the Local Officials And General Comments
								Ravelling	Rutting	Cracking	Other	
5	ER - Port Colborne	Composting Pad -- Landfill site on Elm Street south of Forks Road	HL3 & HL8	1 ha	Nov-93	Still in use (until 2003), no maintenance ever performed	Periodic travel by heavy trucks and other rubber-tired machinery	Minor ravelling	No rutting	No cracking	Some broad settling observed on the portion constructed on waste fill area.	Has performed well.
6	ER - Highway 62 (Under MTO)	Bancroft Southerly 20 km, Station 14+915 to 12+915	--	--	--	Under MTO, but no crumb-rubber asphalt was constructed.	-----	-----	-----	-----	-----	No crumb rubber asphalt was constructed, though proposed earlier. (See Note 2)
7	ER - Bobcaygeon, Highway 36	Beatty to Twp 8th Line 359+50 to 395+75, Contract 79-32 Used dry process	HL-2	--	Sep-80	Resurfaced, probably around 1991. This road is now under the Township of Galway-Cavindish-Harvey.	More than 2000	-----	-----	-----	There was serious deterioration about 8 years after construction and it was resurfaced (probably in around 1991)	Information collected from a past MTO employee. However this road is under the Township of Galway-Cavendish-Harvey and they did not provide any information.
8	ER - Kirkfield, Highway 48	Gravel Rd to Trent River / County Rd. # 9, 35+160 to 35+910, Contract 79-85 Used dry process	HL-4	--	Jul-80	Resurfaced, probably around 1995, according to an ex-MTO employee. This road is now under the City of Kawartha Lake.	(AADT 3500 in 1996)	-----	-----	-----	In general, performance of the road was fair to poor (according to a past MTO employee)	Information collected from a past MTO employee (referred by the local official from the City of Kawartha Lake).
9	NER - Kirkland Lake, Main Street	Birch Street to 325 m south, structure: 1.5 m Gran B; 150 mm Gran A; 80 HL-4	HL-4	0.3	Sep-94	Still exist (not resurfaced), until 2003	AADT 500--600	No ravelling or spalling of aggregates	----	Some longitudinal and transverse cracking.	----	----

Appendix B: Performance of Ontario Rubber Modified Pavements Prior to Resurfacing --- 2003 MTO Survey

Section (Note 1)	Location	Description	Mix Type	Length (km)	Const. Date	Status in 2003	Traffic in 2003 / Prior to Re-surfacing	Ride Quality in 2003 or Prior to Resurfacing				Observation by the Local Officials And General Comments
								Ravelling	Rutting	Cracking	Other	
10	NER - New Liskeard (now under Municipality)	Whitewood Avenue / Highway 65	HL-4	0.76	Jul-93	Resurfaced by MTO in 1999 though earlier transferred to the Municipality. Rubber pavement began to fail shortly after placement and consequently MTO agreed to remove and resurface by HL-4.	AADT 3350	Reported in 1994 that pavement ravelling occurring in rubberized asphalt test section and becoming progressively worse.	----	----	Crumb rubber particles segregated from the exposed asphalt surface causing pockets	From 1994 ravelling was occurring and becoming worse progressively. In 1997 the Town advised MTO that crumb rubber particles are segregating from the exposed asphalt surface and causing pocket of coarse aggregates to be lifted out of the mix.
11	NWR - Northumberland County Rd 9	1 km east of County Rd 18 to County Rd 15	--	2.7	93	Still exists, until 2003	AADT— 1600	Extensive slight ravelling & loss of aggregate	Frequent moderate rutting	Extensive slight to moderate transverse & longitudinal cracking. Frequent slight alligator cracking	Ride Comfort Rating is "FAIR"	----
12	NWR - Northumberland County Rd 18	County Road 74 to 1.7 km North	--	1.7	93	Still exists, until 2003	AADT -- 4600	Extensive moderate ravelling & loss of aggregate	Extensive moderate rutting	Frequent Slight transverse and centre line cracking. Frequent severe longitudinal cracking.	Ride Comfort Rating is "FAIR"	----

Appendix B: Performance of Ontario Rubber Modified Pavements Prior to Resurfacing --- 2003 MTO Survey

Section (Note 1)	Location	Description	Mix Type	Length (km)	Const. Date	Status in 2003	Traffic in 2003 / Prior to Re-surfacing	Ride Quality in 2003 or Prior to Resurfacing				Observation by the Local Officials And General Comments
								Ravelling	Rutting	Cracking	Other	
13	NWR – Fort Frances	Old Shamble Rd (previously recorded as River Rd)	HL-4	0.25	Oct-93	Still exists, until 2003	AADT 400--500	Slight aggregate loss but no potholes	No Rutting	___	Cracking --- Longitudinal Joint Failure	Need repairing due to longitudinal joint failure
14	NWR - Fort Frances	Armit Avenue	HL-4	0.1	Oct-93	----	AADT 1000--1200	Slight aggregate loss	No Rutting	No Cracking	----	Still in good condition
15 & 16	SWR - Grey County Road 9	4 km west of Hopeville to 3 km east of Hopeville and 3 km east of Hopeville to County Road 8	HL-4	6.9 + another 7.1km	Aug-95 and Oct-94	----	----	----	----	----	----	Grey County has provided information for 3 out of the 5 roads in their area where crumb-rubber modified asphalt pavement constructed. Information for this road not received.
17	SWR - Grey County Road 40 (previously known as Road 4)	Highway 6 to Desboro	--	11.2	93	Still exists (not re-surfaced)	AADT 1050	Some ravelling	No signs of rutting	No transverse cracking. Some longitudinal cracking along edges	There is a cold joint along the centre. No other pavement distresses.	According to the local officials, the road was paved quite late in the fall (November) and the contractor heated the asphalt too high to compensate for the cold temperature. There is some evidence of burning. However, this rubberized asphalt road is standing up well for about ten years (still to-date) and looks good.
18	SWR - Grey County Road 13	Highway 4 to Eugenia	HL-4 surface	2.7	92	Still exists, until 2003. No spray patching or crack filing applied so far.	AADT 2450	No evidence of ravelling or stone pop out	No evidence of rutting on either the northbound or southbound lanes	No transverse cracking, some longitudinal cracking along the edges.	No other pavement distresses	According to the local official construction of this road was done by adding crumb rubber during the cold in place recycling process. But no crumb rubber used on the top surface of HMA. This road performed quite well (both looks and rides good) for 11 years still to-date.
19	SWR - Grey County Road 12	Highway 6 to Markdale	HL-4	12.3	Nov-91	----	----	----	----	----	----	Information for this road not received.

Appendix B: Performance of Ontario Rubber Modified Pavements Prior to Resurfacing --- 2003 MTO Survey

Section (Note 1)	Location	Description	Mix Type	Length (km)	Const. Date	Status in 2003	Traffic in 2003 / Prior to Re-surfacing	Ride Quality in 2003 or Prior to Resurfacing				Observation by the Local Officials And General Comments
								Ravelling	Rutting	Cracking	Other	
20	SWR - Maryborough Sideroad 6 (previously recorded as Sideroad 7)	Highway 86 to Concession 3	HL-4	2.7	Nov-93	Resurfaced on Aug-2002	AADT -- 500	Minor ravelling and small potholes in some portion	No rutting	Centre line separation. Also few transverse cracking, meandering cracking and alligator cracking.	Rubber crumb tended to remain with loss of fines around the crumb	Very satisfied with overall performance and durability
21	SWR - Haldimand County, Regional Rd 55	Regional Rd 9 to Regional Rd 20	HL-3	4.8	Oct-90	Resurfaced partly in 2000 and partly in 2002	AADT -- 965	Severe ravelling and popping out of aggregates	slight rutting	Some alligator cracking and longitudinal cracking and severe transverse cracking	Early deterioration noticed after 6 to 7 years	Performed very poorly and early deterioration noticed after 6 to 7 years and life is about half of a normal HMA, according to local officials. Aggregates flexes around crumb-rubber particles.
22 & 23	SWR - Norfolk County, Regional Rd 9	Villa Nova to Regional Rd 70 and Regional Rd 70 to Regional Rd 55	HL-3	3.3+ another 3.8km	Oct-90	Milled and resurfaced with HL3 in 2001 and maintenance was ongoing for approx. 5 previous years (patching potholes, cracks, etc.)	AADT -- 2000 and Commercial 5%	Severe potholes	No rutting	Centerline cracking. Medium to high severity longitudinal, transverse, and alligator cracking.		Resurfaced in 2001. However, maintenance undertaken for approx. 5 previous years (patching potholes, cracks, etc.). Showed evidence of ravelling/potholes approximately 6-7 years after initial project of 1990. Very poor performance.
24	SWR - Highway 400	0.6 km north of Highway 89 to 3 km north	--	0.5	Jul-90	Resurfaced under contract 96-11, to address rutting & crack repair	AADT 75000, Truck 12.7%	----	Severe Rutting	Severe Longitudinal and Transverse Cracking		Resurfaced in 1996 due to severe rutting and cracking
25	SWR - Brantford, Park Road North	Dunsdon Street to Powerline Road	--	0.5	Oct-94	Still exists (not re-surfaced so far), until 2003	AADT -- 1000	Slight aggregate loss but no potholes	No rutting	Extensive Longitudinal and Transverse Cracking		According to the local official, this road will require extensive maintenance repairs within the next 5 years due to severe cracking.

Appendix B: Performance of Ontario Rubber Modified Pavements Prior to Resurfacing --- 2003 MTO Survey

Section (Note 1)	Location	Description	Mix Type	Length (km)	Const. Date	Status in 2003	Traffic in 2003 / Prior to Re-surfacing	Ride Quality in 2003 or Prior to Resurfacing				Observaiion by the Local Officials And General Comments
								Ravelling	Rutting	Cracking	Other	
26	SWR - Barrie Township (Actually neither in City of Barrie nor in Simcoe County)	Mazinaw Lake Road South	--	1	Oct-93	----	----	----	----	----	----	Unable to identify the location after extensive searching. This road is not under the City of Barrie nor with the Simcoe County.
27	SWR - Windsor	Wildwood Drive	--	0.3	Nov-93	Road surface was in good condition and there was no maintenance work until 2003	AADT 500 to 1000	No potholes, only minor ravelling	No rutting	Some alligator cracking		In good condition and no maintenance to date. According to the local officials there is nothing remarkable about this pavement and any HL3 would perform in the same manner.
28	SWR - Wi	Beachdale Road	--	0.5	Nov-93	Road surface was in good condition and there was no maintenance work until 2003	AADT 500 to 1000	No potholes, only minor ravelling	No rutting	Some alligator cracking	---	In good condition and no maintenance to date
29	SWR - Windsor	Esplanda Drive	--	0.4	Nov-93	Road surface is in good condition and there was no maintenance work until 2003	AADT 500 to 1000	No potholes, only minor ravelling	No rutting	Some alligator cracking	---	In good condition and no maintenance to date
30	SWR - Cambridge	Stanley Street	HL-4 base and conventio nal surface	0.5	Nov-93	There was no need of re-surfacing, until 2003	ADT 256 (Commerci al 0%)	None	None	None	---	According to the local officials the road is in excellent condition.
31	SWR - Grey County	County Road 17, from Grey Road No. 17 A to Grey Road No. 170 (Ben Allan to Copper Kettle)	1999 (as per local officials)	4.4	----	Not resurfaced (but it had some spray patching), until 2003	AADT -- 1600	No ra ... ling	Some rutting is evident	There is some longitudinal cracking, but no transverse cracking	No other pavement distresses	According to the local officials, the road is in good condition considering the daily use of heavy trucks (quarry operation). Currently it has a 40 mm lift. Besides, this road passes through a swampy area.

Appendix B: Performance of Ontario Rubber Modified Pavements Prior to Resurfacing --- 2003 MTO Survey

Section (Note 1)	Location	Description	Mix Type	Length (km)	Const. Date	Status in 2003	Traffic in 2003 / Prior to Re-surfacing	Ride Quality in 2003 or Prior to Resurfacing				Observation by the Local Officials And General Comments
								Ravelling	Rutting	Cracking	Other	
32	SWR - Thamesville, Highway 2	East of Hwy 21 Used dry process	HL-4 modified	6.5	90	Under Municipality of Chatham-Cant (transferred from MTO in 1997). Still exists (not resurfaced), until 2003	AADT --- 2900 & Truck --- 8% in 1992 (informed by local officials)	Slight aggregate loss (0-10%) on entire road way	Slight rutting throughout cross-section	Moderate longitudinal and alligator cracking and some transverse cracking	Maintenance patching ----minor along edge	According to local officials, in overall the road looks good, though well travelled in 13 years. Wearing of roadway is uniform throughout cross-section
33	SWR - Bentinck Township	Sideroad 25	HL-4	3	Oct-93	Still exists (no re-surfacing done so far), until 2003	AADT --- 750	No Potholes	No Rutting	Moderate transverse cracking and some longitudinal cracking		As good as normal asphalt (provided the base is good)

Note:

1. No CRM asphalt pavement had ever been constructed on Highway 62 (i.e. Section 6), as revealed during 2003 MTO Survey. Therefore, the total number of trial sections is 32, though the last section number is 33 in this Appendix.

2. The terms used to describe the CRM pavement locations with respect to MTO Regions are:
CR = Central Region
ER = Eastern Region
SWR = Southwestern Region
NER = Northeastern Region
NWR = Northwestern Region.

Appendix C: US DOT Adoption of Rubber Modified Asphalt Pavement Technology

US DOTs	Contact	Survey (Caltrans, Oct 2004) Information	Information Collected By MTO (Dec. 2004)	Remarks
OVERALL (From Caltrans Survey)		Summary of Catrans Survey (Result Circulated in Oct 2004) 44 DOTs responded, 5 DOTs (or 11 % DOTs) were using wet process and another 2 DOTs were still experimenting during the time of this survey conducted by Caltrans.		
ARIZONA DOT	Jim Delton jdelton@dot.state.az.us	From website: quietroads.com During the time of this survey, ADOT has more than 2500 miles of highways with ARFC (Asphalt Rubber Friction Course) as the final wearing surface on both asphalt and concrete pavements. ARFC improves smoothness, reduces cracking, provides adequate skid resistance and excellent durability. More recently ADOT has begun using ARFC as a tool to reduce freeway noise.	Information from emailed response: • They only use wet process • They generally use only in the top layer(s) • Overall performance GOOD to EXCELLENT of those ARFC constructed more than 8 to 10 years ago, though Traffic levels are high. • Above technology is suitable for roads of high traffic volume • They have sections over 10 years old still performing well on high traffic interstates. • They have adopted this technology on full scale basis • They have tried some test sections with dry process, and they did not performed adequately.	• **Adopted** this technology • Only uses **wet process**
RHODE ISLAND DOT	Colin Franco cfranco@dot.state.ri.us, mfelag@dot.state.ri.us	For 6-7 years they are using crumb rubber successfully in crack sealing, thin mix overlay, chip seal, OGFC and SMA. In future they will use OGFC on high speed road (being used in crack sealant & thin mix overlay (PG 70-40 & -34 in 1 in. lift) for pavement preservation & chip seal (very effective in stopping reflecting crack). Next step is to use crumb-rubber modified PGAC 76-34 in modified friction mix & OGFC (on high speed road) and SMA at intersection. Working with a company & university on the technology.	Information from emailed response: • They are not using dry process in their modified friction course, thin mix overlay, SMA & OGFC as it failed miserably when they have tried. • Using special chemically modified wet process in their crack sealing and chip-sealing, where the rubber dissolves and links to the asphalt polymer. They do not see any bits of rubber in the AC. • This is a new technology which being used for the last 4 years prior to Caltrans Survey. All the roads (even heavily traffic) were performing very well. • They are using it for pavement preservation program and over the last two years their design section is using it for specific projects on high volume roads. It adds $10 to a ton of asphalt mix which costs $35/40 per ton.	• **Adopted** this technology • Use **wet process**

Appendix C: US DOT Adoption of Rubber Modified Asphalt Pavement Technology

US DOTs	Contact	Survey (Caltrans Oct 2004) Information	Information Collected By MTO (Dec. 2004)	Remarks
CALTRANS (California DOT)	Phil Stolarski phil_stolarski@dot.ca.gov Terrie Bressette Ph: 916-227-7303	Until 2003 used CRM in gap and open-graded mixes as well as asphalt rubber chip seal	Information from emailed response: • Has a long history of using rubberized asphalt concrete (RAC). Most of their experience is in using field mixed, high viscosity wet process binder. At present, they have a consultant to investigate processes and strategies to review other user agencies' processes and strategies, and recommend changes that might lead to increased use of crumb rubber modified products. They will be posting the products coming out of that contract to their pavement website: http://www.dot.ca.gov/hq/oppd/pavement/guidance.htm. The Asphalt Rubber Usage Guide is posted there. • Specifications for RAC are available from the web site: http://www.dot.ca.gov/hq/esc/oe/specifications/SSPs/99-SSPs/. • They have constructed 2 projects using the dry process and 1 recent test section. All installations were designed as gap-graded and have been used as surface courses. • Caltrans uses the wet process for the AC used in asphalt rubber chip seals. • Caltrans has used both wet process gap-graded and wet process open graded AC on high volume roads with success. Has also used rubber chip seals on high volume roads with success, but restricted chip seals in general to lower volume roads (just due to windshield breakage in the first stages on high speed/high volume roadways). • They have locations where this technology performed well for more than 10 years. Also have some older rubber asphalt chip seals that are on lower volume roads in the southern part of the state that have been in place for more than 10 years and are performing well. They generally assume a 5 to 7 year life for chip seals. • They use the technology, including rubber asphalt chip seals as standard strategies.	• **Adopted** this technology • Use **wet process**
PENNSYLVANIA DOT	Dean Maurer demaurer@dot.state.pa.us	Has long-term evaluated recycled rubber from tires (since mid 1960's) and still experimenting. Will remain experimental until proved cost effective application found. Only crack sealant was proved effective from cost/benefit viewpoint. But now a days, crack sealants no longer being field blended, rather supplied pre-packaged.	• We have some information from the survey and on the other hand further information could not be collected after several attempts.	• Were using **experimentally** (mainly by **wet process**)

Appendix C: US DOT Adoption of Rubber Modified Asphalt Pavement Technology

US DOTs	Contact	Survey (Caltrans, Oct 2004) Information	Information Collected By MTO (Dec. 2004)	Remarks
FLORIDA DOT	Jim Musselman jim.musselman @dot.state.fl.us Ph: 352-955-2905	Currently uses crumb rubber in fine-graded friction course and open-graded friction course, and also as One Spray Application (as asphalt rubber SAMI)	Information from email response: • Only uses wet process in fine graded and open-graded friction course. Once they have tried dry process on small test section in 1989 and it performed very poorly. • They use wet process with their Asphalt Rubber SAMI (blend 20% 20 mesh rubber with a PG64-22 binder. Blending temperatures are approximately 350 - 375 degrees F). • Fine-graded and open-graded friction course and Asphalt Rubber SAMI are suitable for roads of high traffic volume (state roads, US and Interstate highways) and they use asphalt rubber in probably 95% of paving projects. • They have adopted the use of ground tire rubber as a standard construction practice beginning in January 1994. And they have many high traffic projects where the performance is very good to date. • They have adopted this technology on full scale in 1994	• Adopted **this technology** • Only use **wet process**
NEBRASKA DEPARTMENT OF ROADS	Robert C. Rea rrea@dor.state.ne.us (not US DOT) Ph: 402-479-4677	Using crumb rubber as a modifier on a R&D basis. Currently bid 2 to 3 projects/year & are evaluating their effectiveness. Project so far: several gap-graded and open-graded hot mixes on interstate expressway to low volume roads. Also one spray applied chip seal.	Information from email response: • Currently use the wet process, on 2 to 3 projects per year. • Primarily use open-graded mix on High (10 to 30 million ESALS) volume and gap-graded mix on both High and Low (< 1 million ESALS) volume roadways. • Primarily use in the surface course. • Oldest pavement using this technology is only 4 years old. They have just begun to try new mix designs and monitor their performance over the next several years	• Using **wet process experimentally**
TEXAS DOT	Magdy Mikhail MMIKHAI@dot.state.tx.us	Using crumb rubber in seal coat and SMA (asphalt rubber with seal-coat, with permeable friction course or PFC mixes, and SMA mixture).	• Not able to collect more information after several attempts.	• **Adopted** this technology • Use **wet process**